# The Impact of Exhaust Recirculation & Oxygen Enrichment on Gas Turbine Power Plants

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# Outline

- Motivation for Study
- Some Gas Turbine Basics
- Modeling Results
  - Air-blown systems
  - Oxygen-enriched systems
- Conclusions

# Motivation

- There has been a lot of investigation into the concepts of exhaust recirculation and $O_2$ enrichment to increase the $CO_2$ concentration of GT exhaust
- None of these investigations have focused in detail on how this will impact the performance of an existing gas turbine

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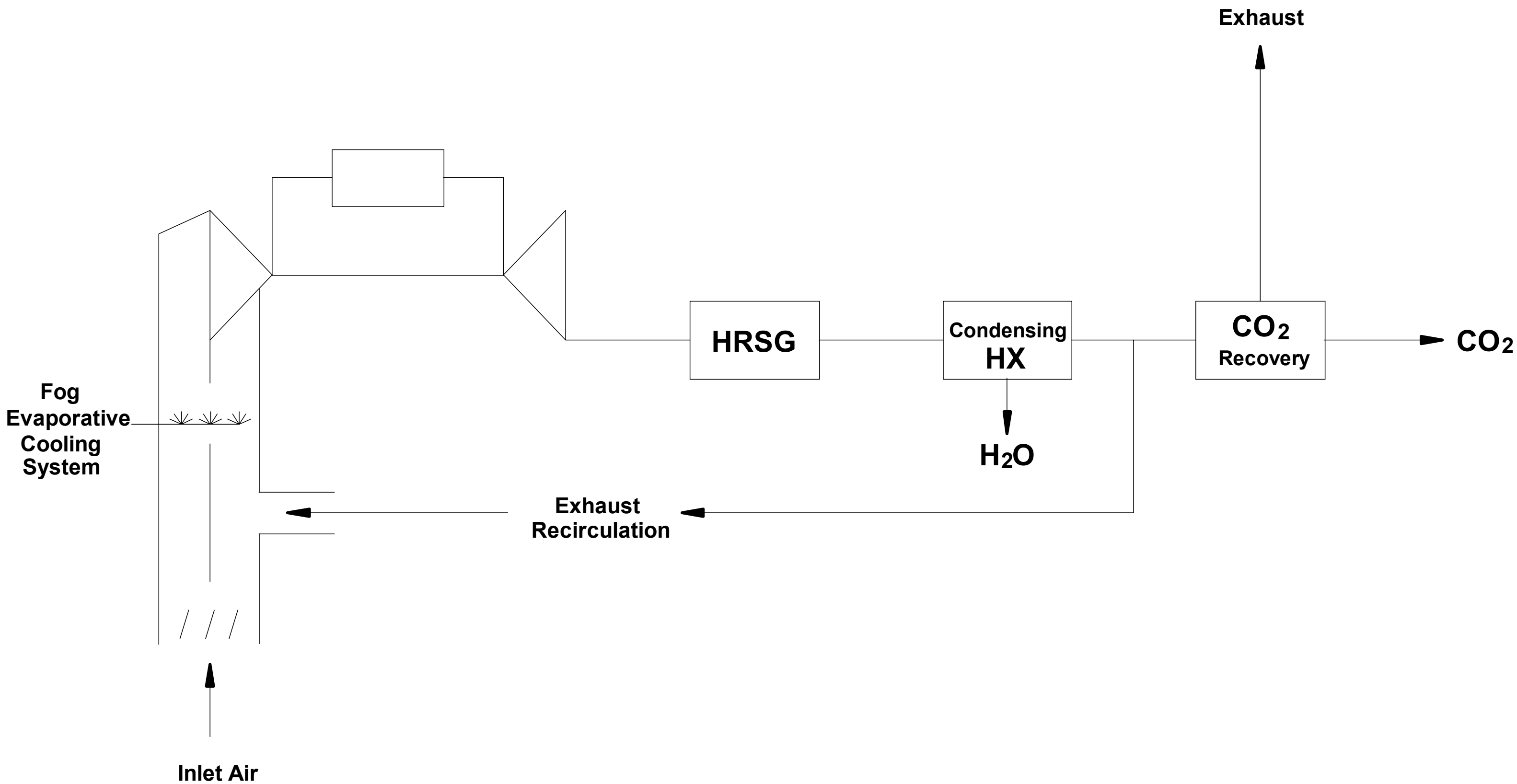
# Simplified Cycle Diagram

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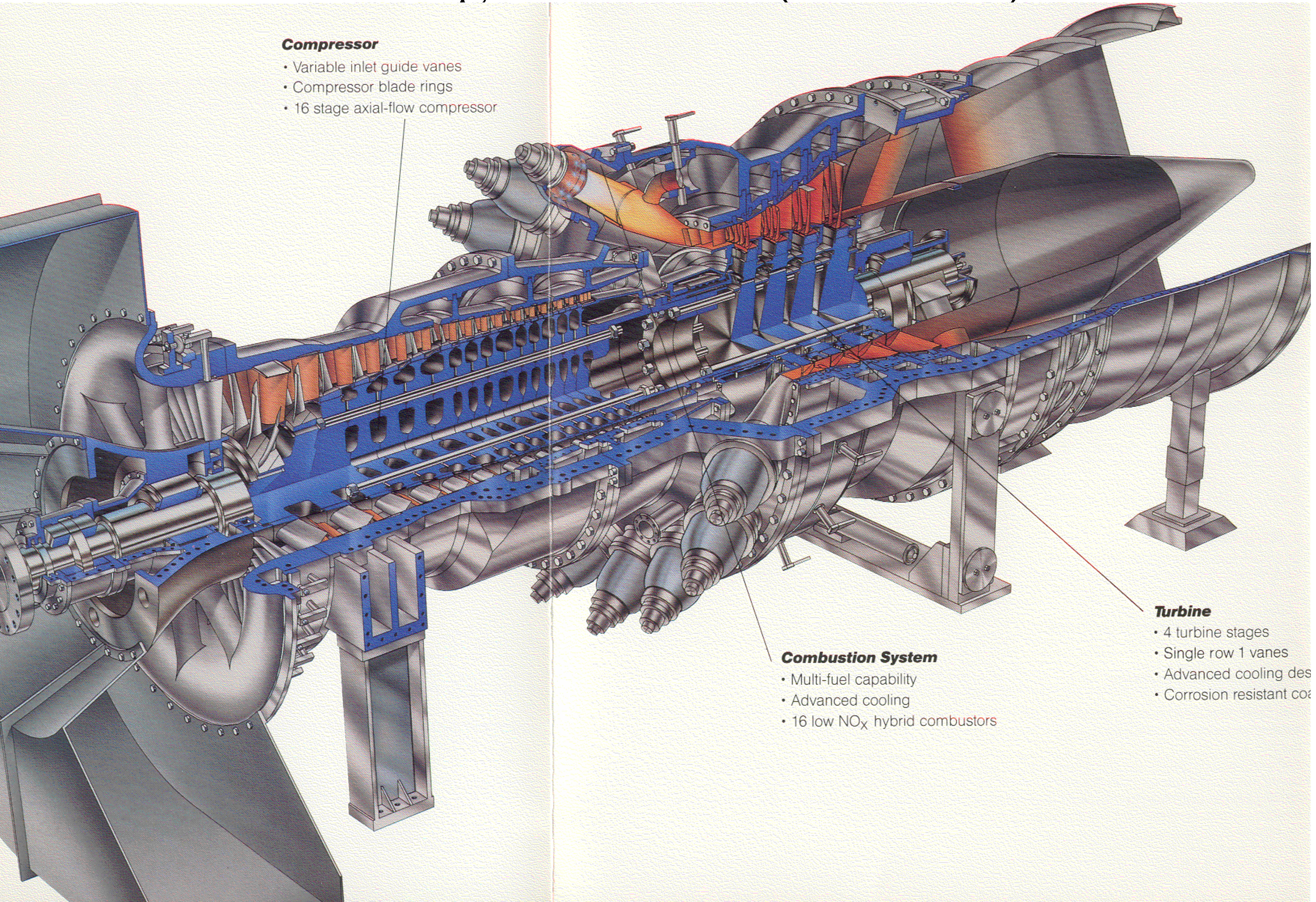
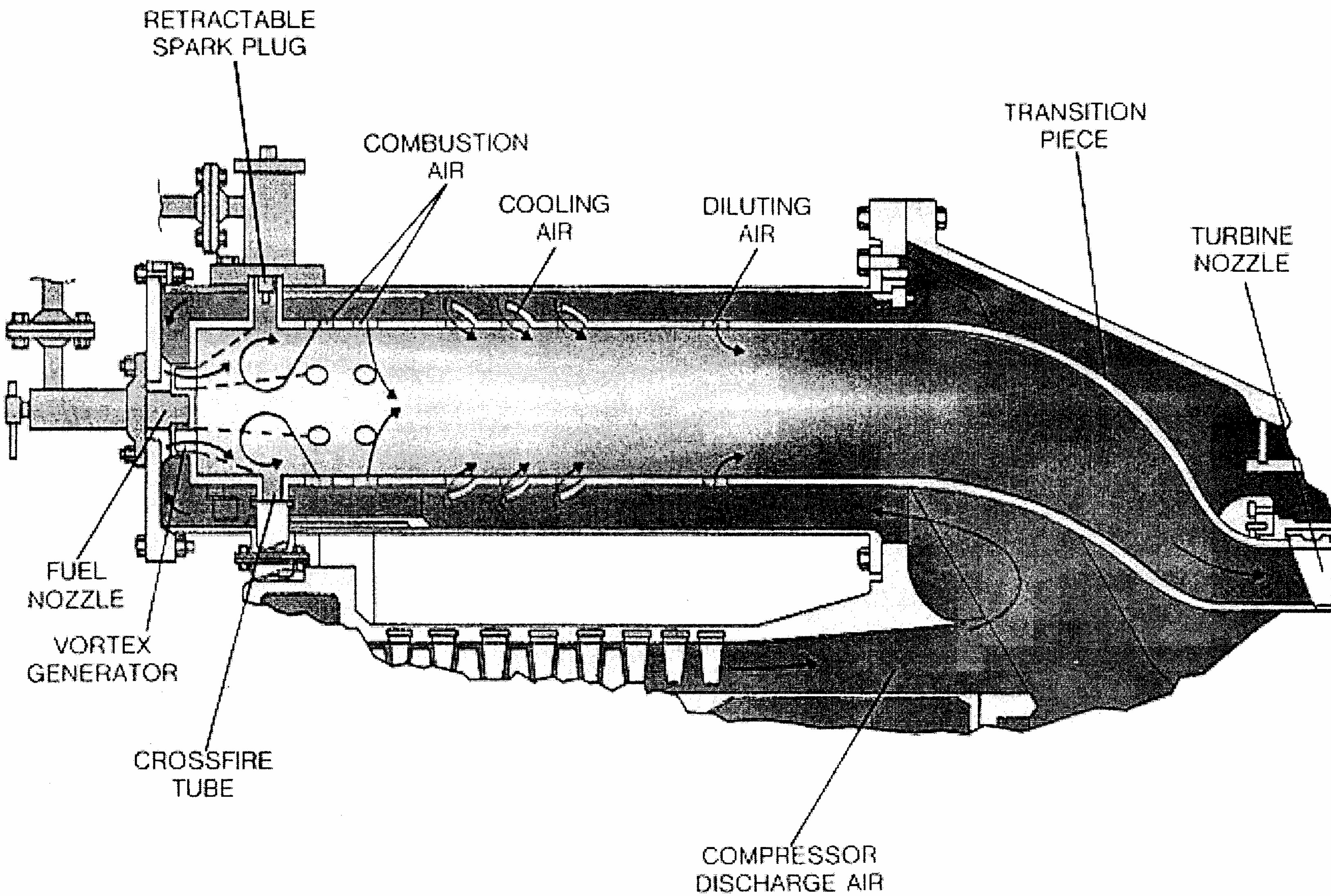
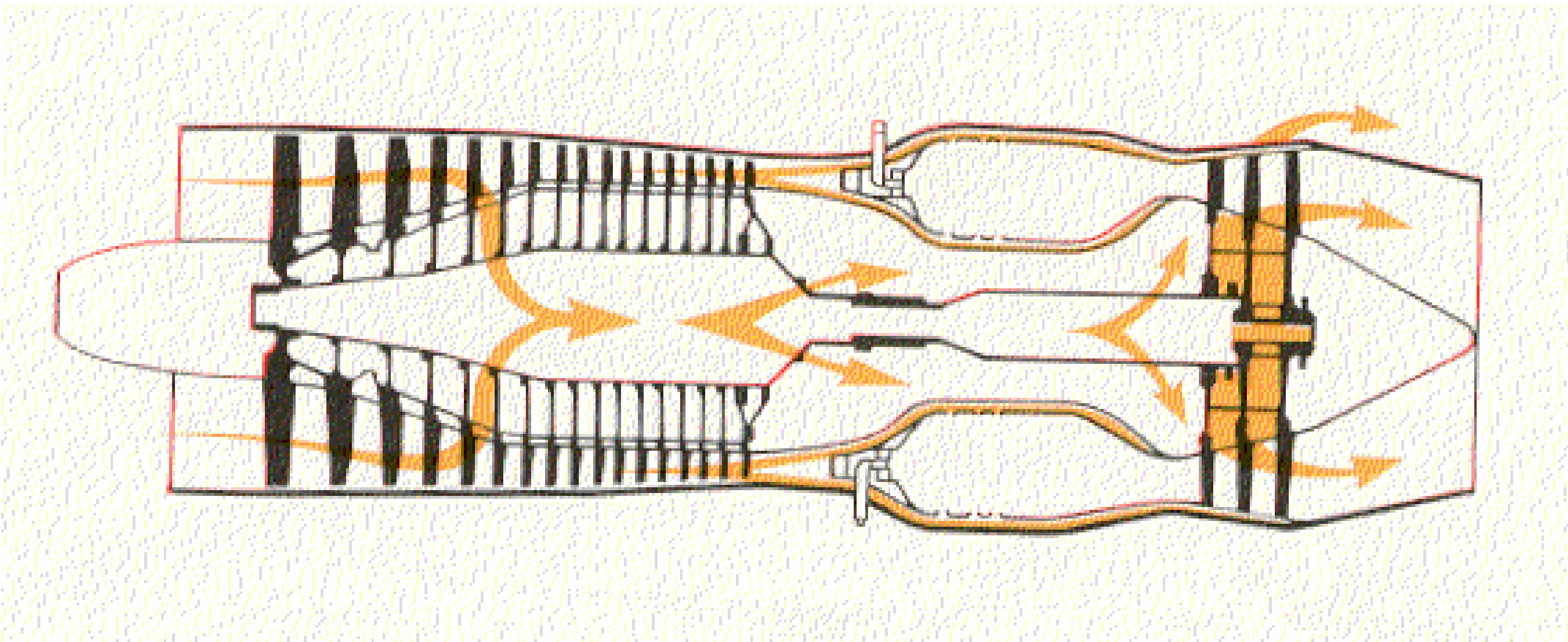
# Westinghouse 501F (180 MW)



# Typical Combustor Design

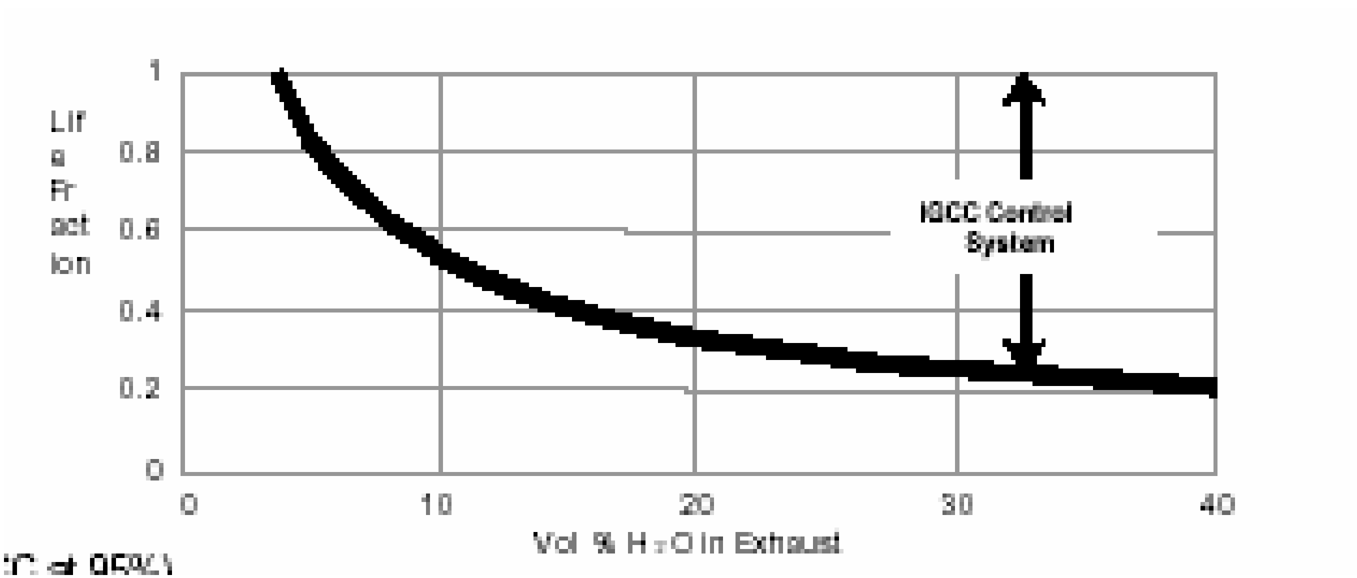


# Simplified Cooling Air Flow Path

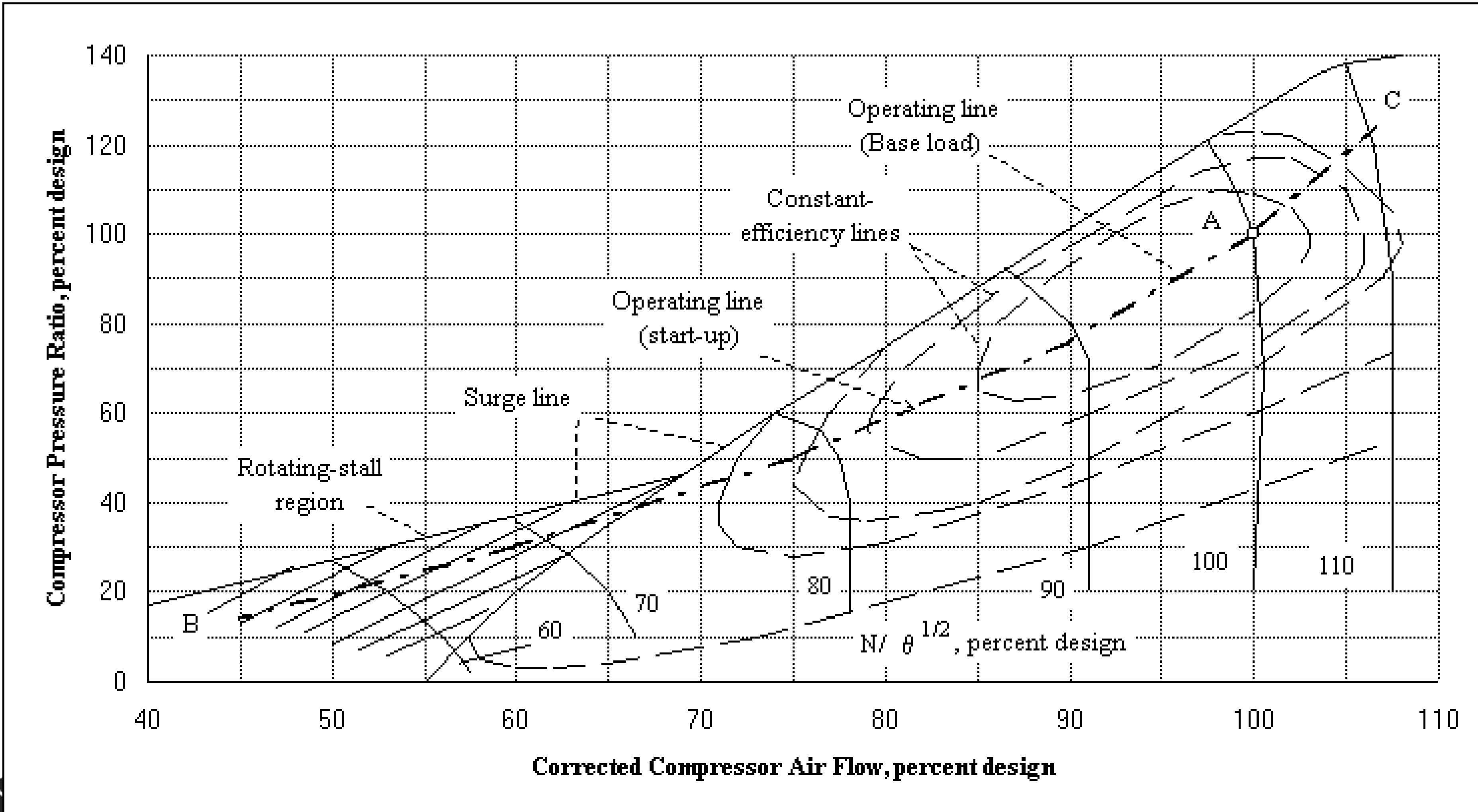


**Rolls Royce Avon**

# Impact of H2O on Parts Life



# Compressor "Map" With Surge Line



# Compressor Parameters

Corrected air flow is defined as:

$$W_{corr} = W_{meas}\sqrt{\theta}/\delta$$

And corrected speed is defined as:

$$N_{corr} = N_{meas}/\sqrt{\theta}$$

Where

$$\theta = \frac{T_{Inlet-meas}}{T_{Inlet-rated}}\frac{MW_{rated}}{MW_{meas}}$$

and

$$\delta = \frac{P_{Inlet-meas}}{P_{Inlet-rated}}$$

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# What happens as you recycle $CO_2$?

$$\boxed{\theta = \frac{T_{Inlet-meas}}{T_{Inlet-rated}} \frac{MW_{rated}}{MW_{meas}}}$$

- Mole Wt of $CO_2$ is 44, which is much higher than ambient air (circa 29).
- Theta decreases unless inlet temperature increases to compensate
- Alternatively, more $H_2O$ (mole wt = 18) could be recycled also to maintain mole wt of exhaust near 29

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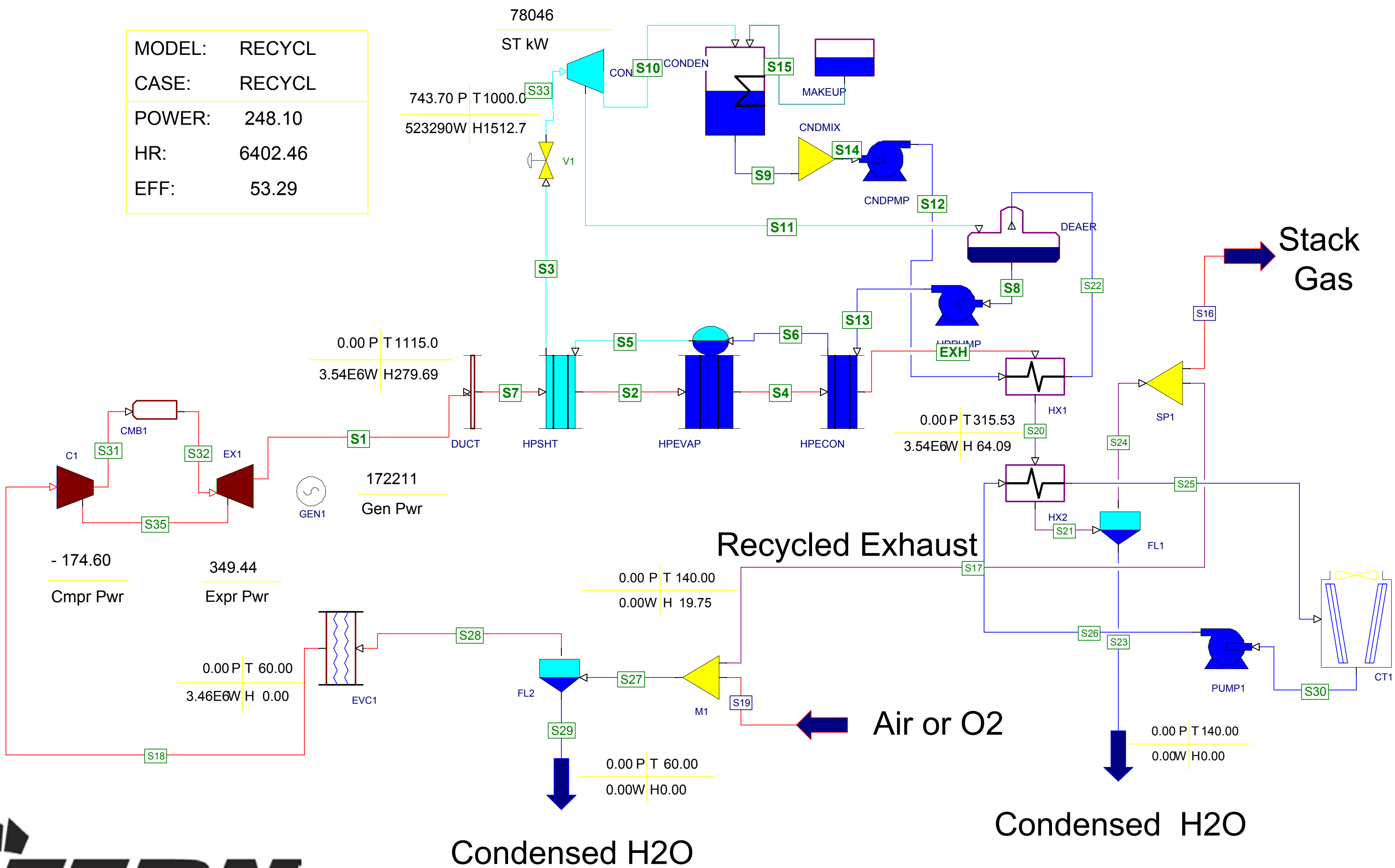
# GateCycle Model Diagram

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# Air-Blown Recycle Results

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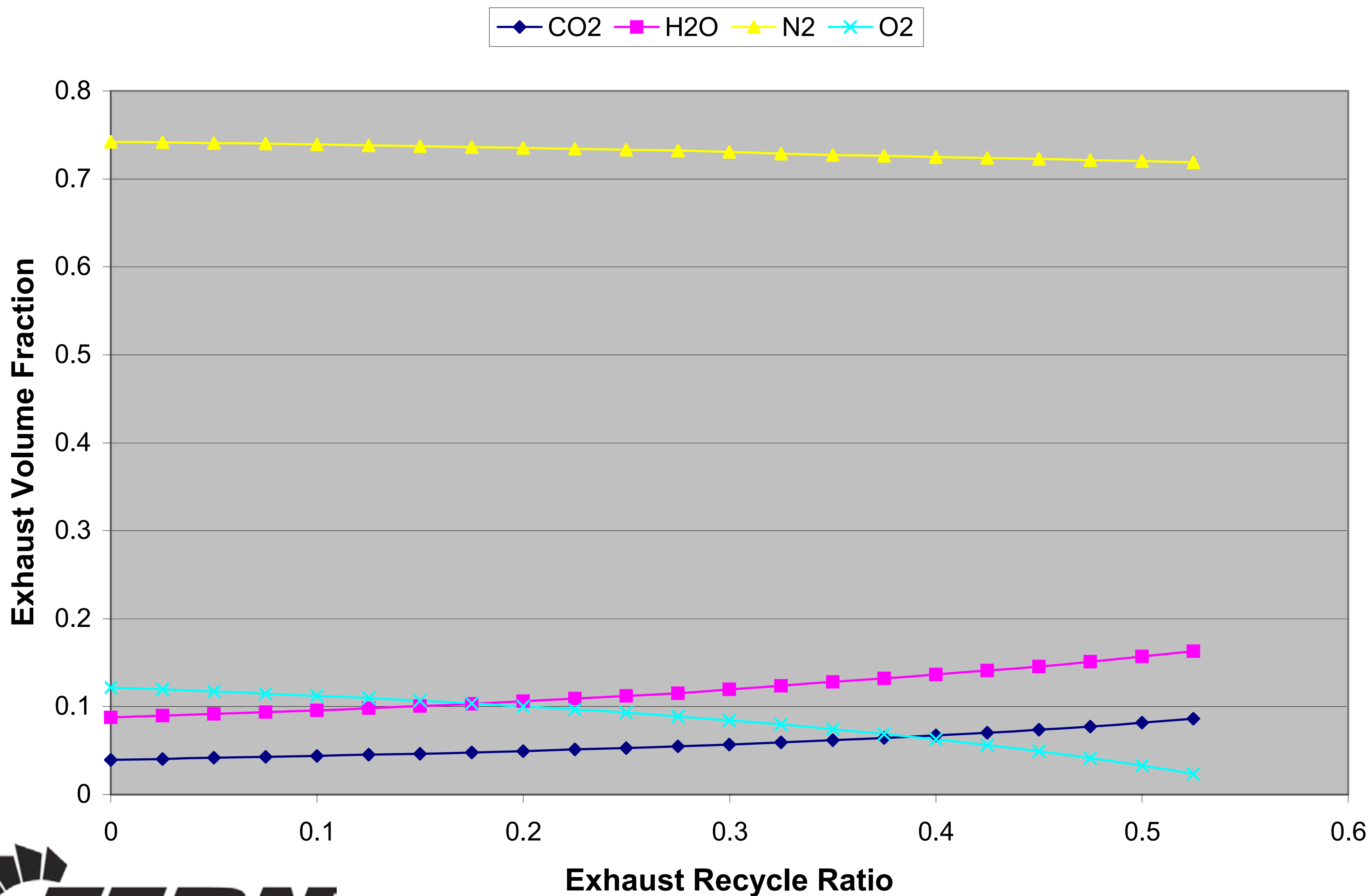
## Impact of Exhaust Recycle on Air-Blown GT

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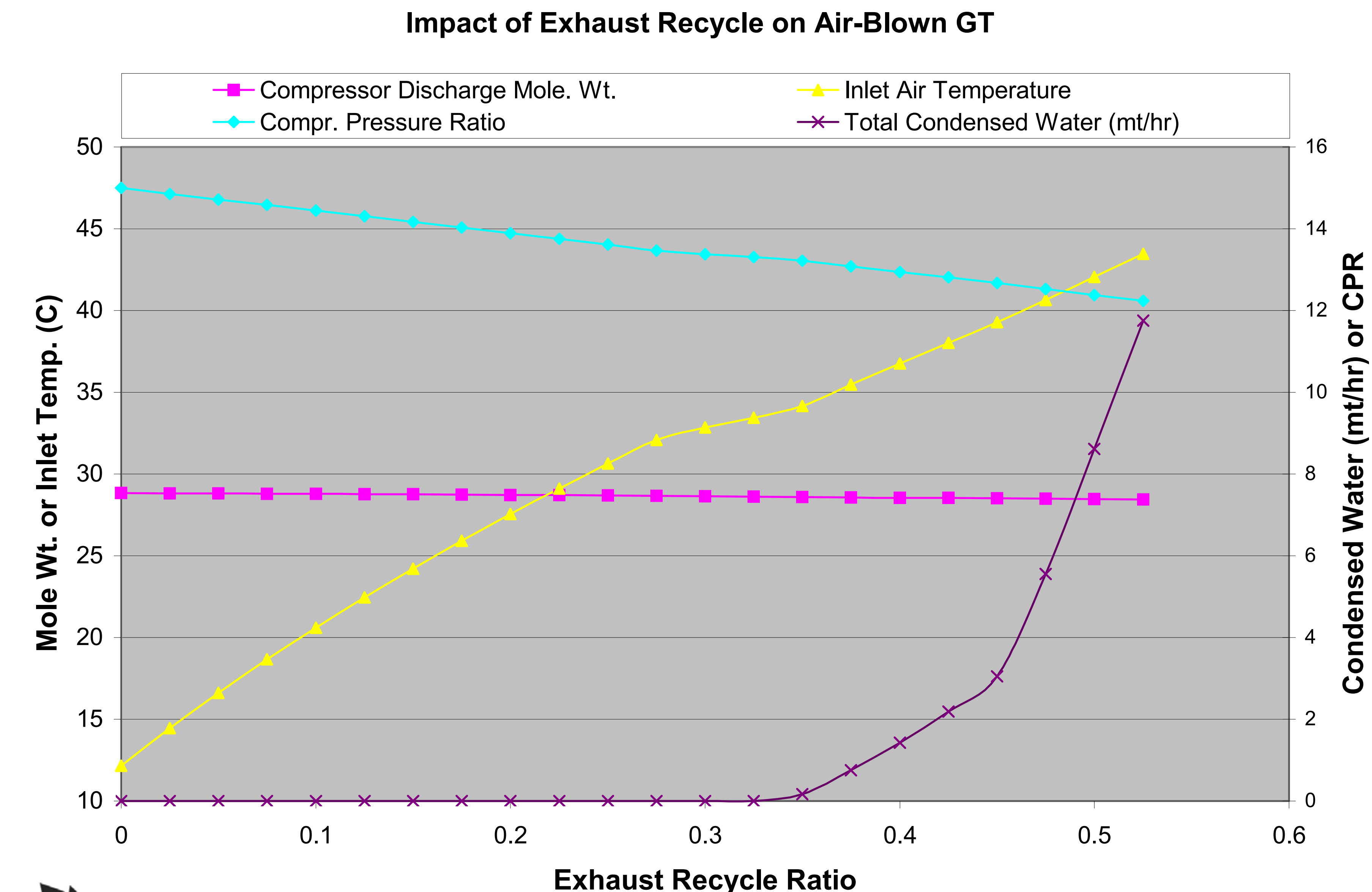


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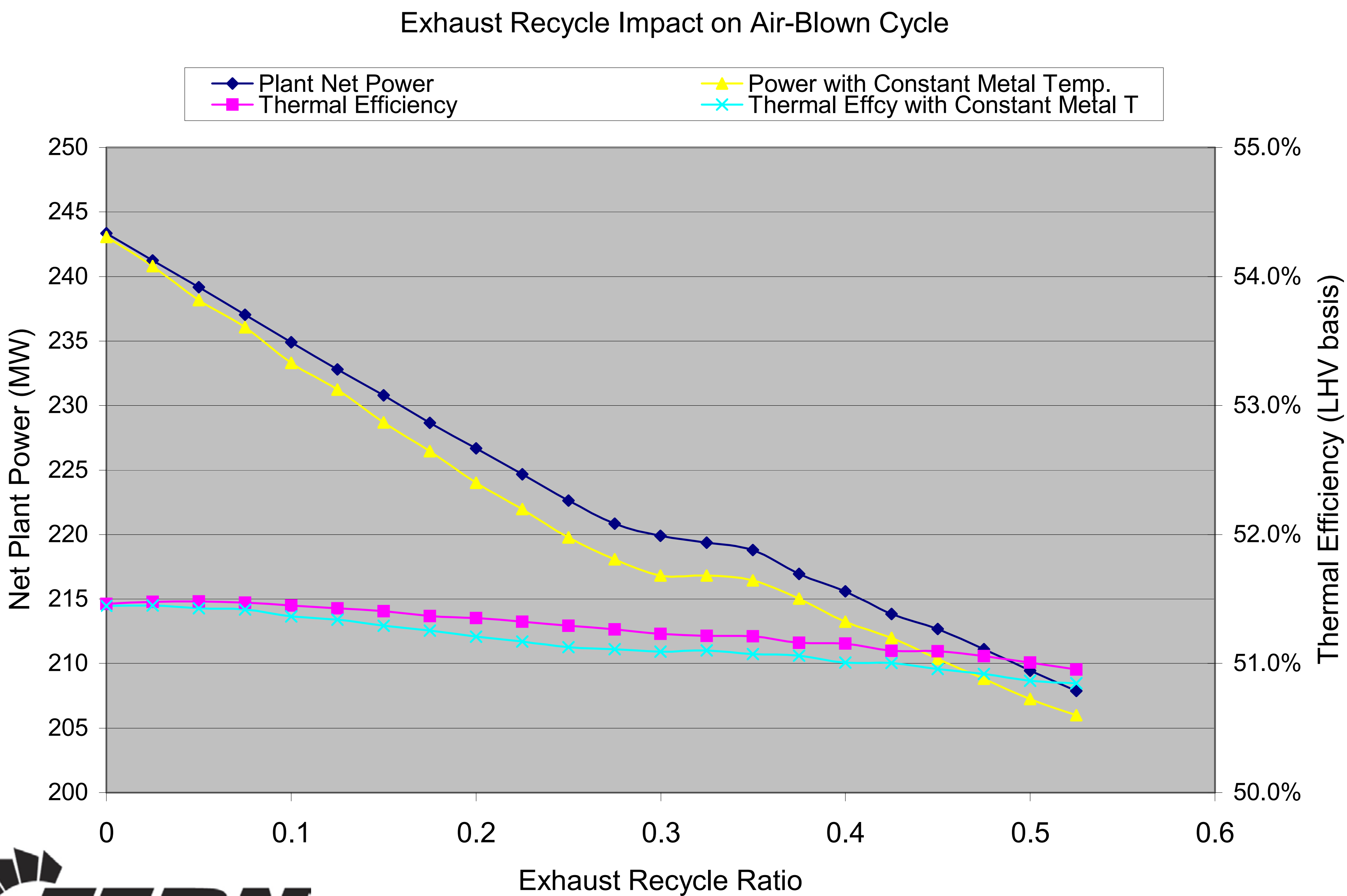


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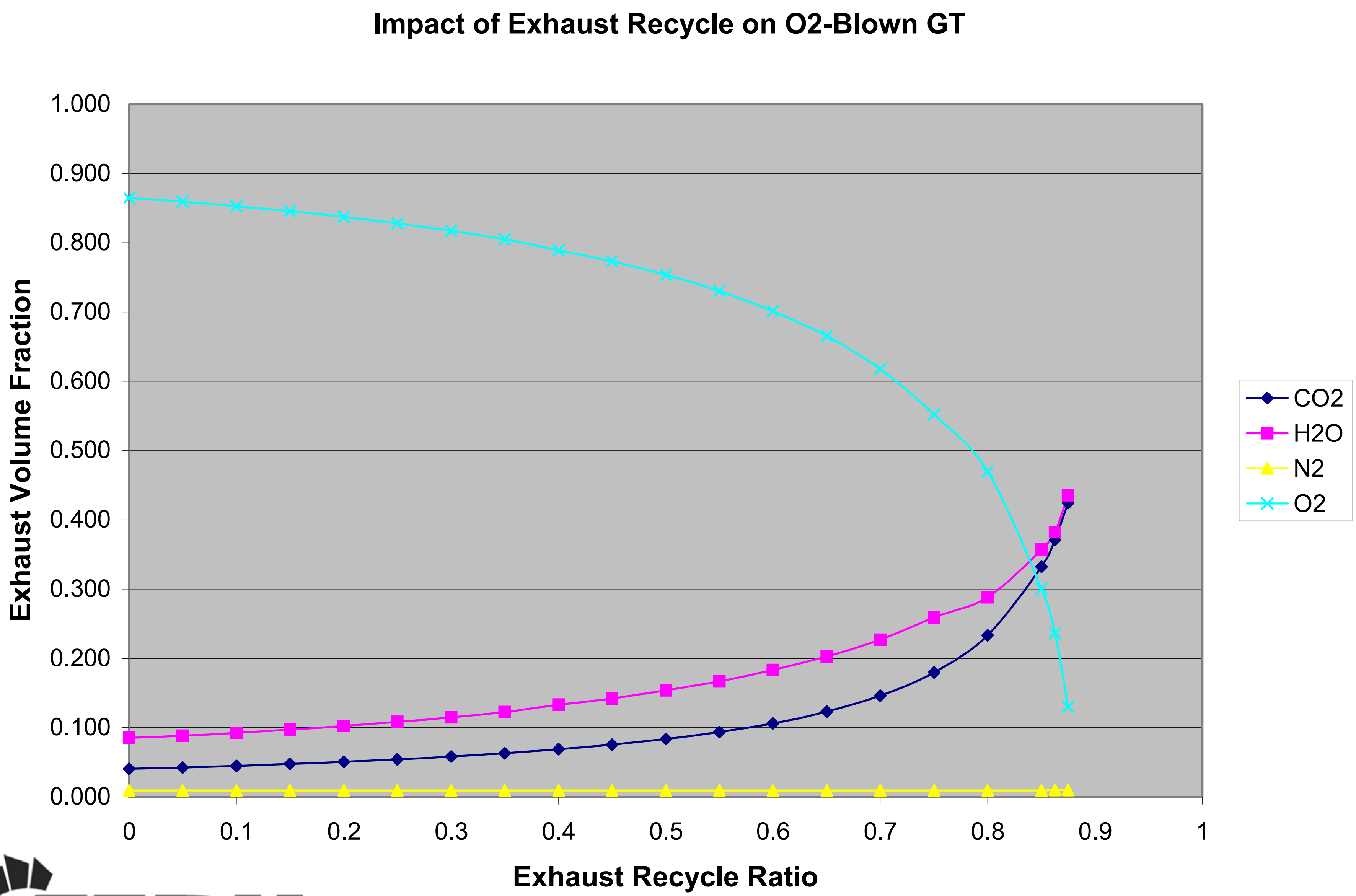
# O2-Blown Recycle Results

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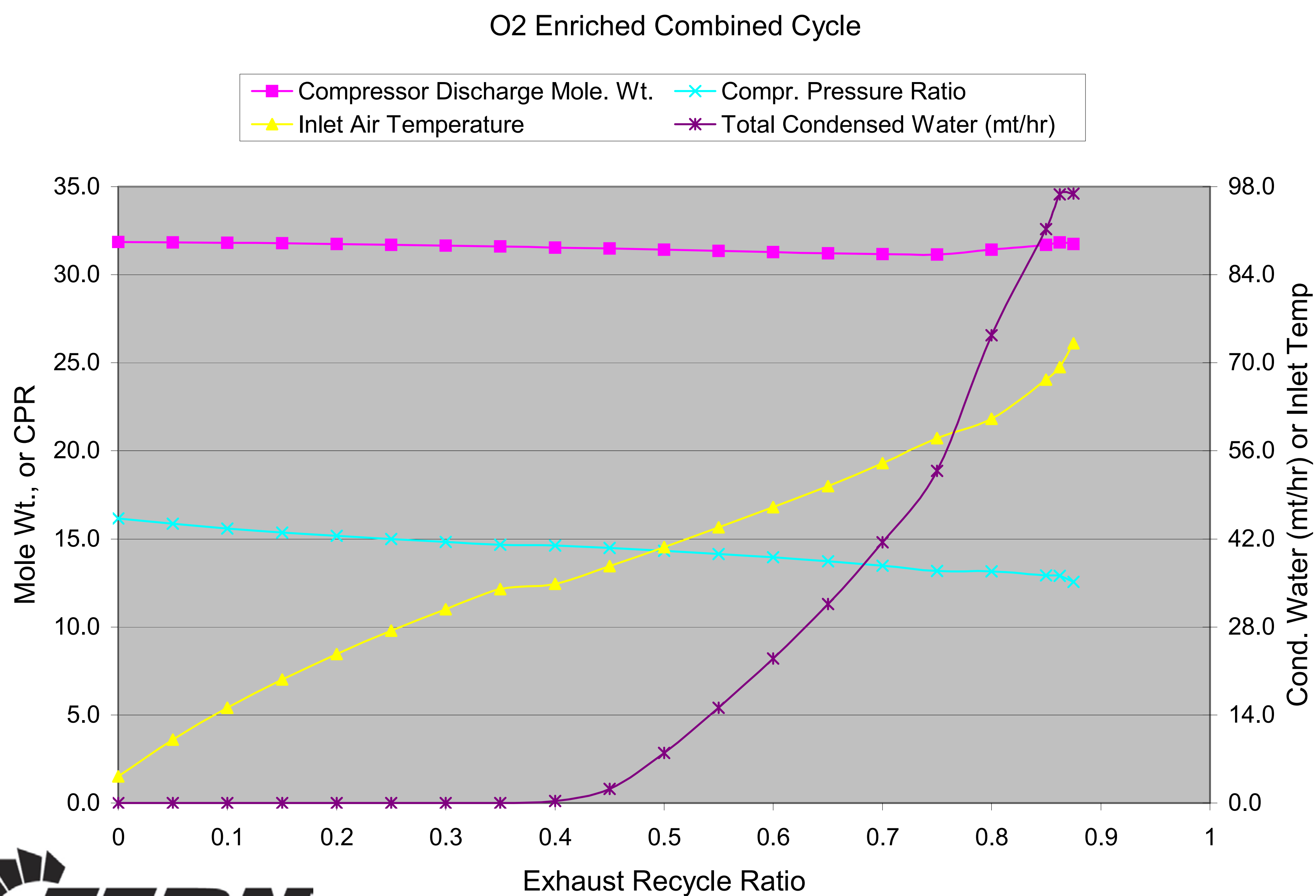


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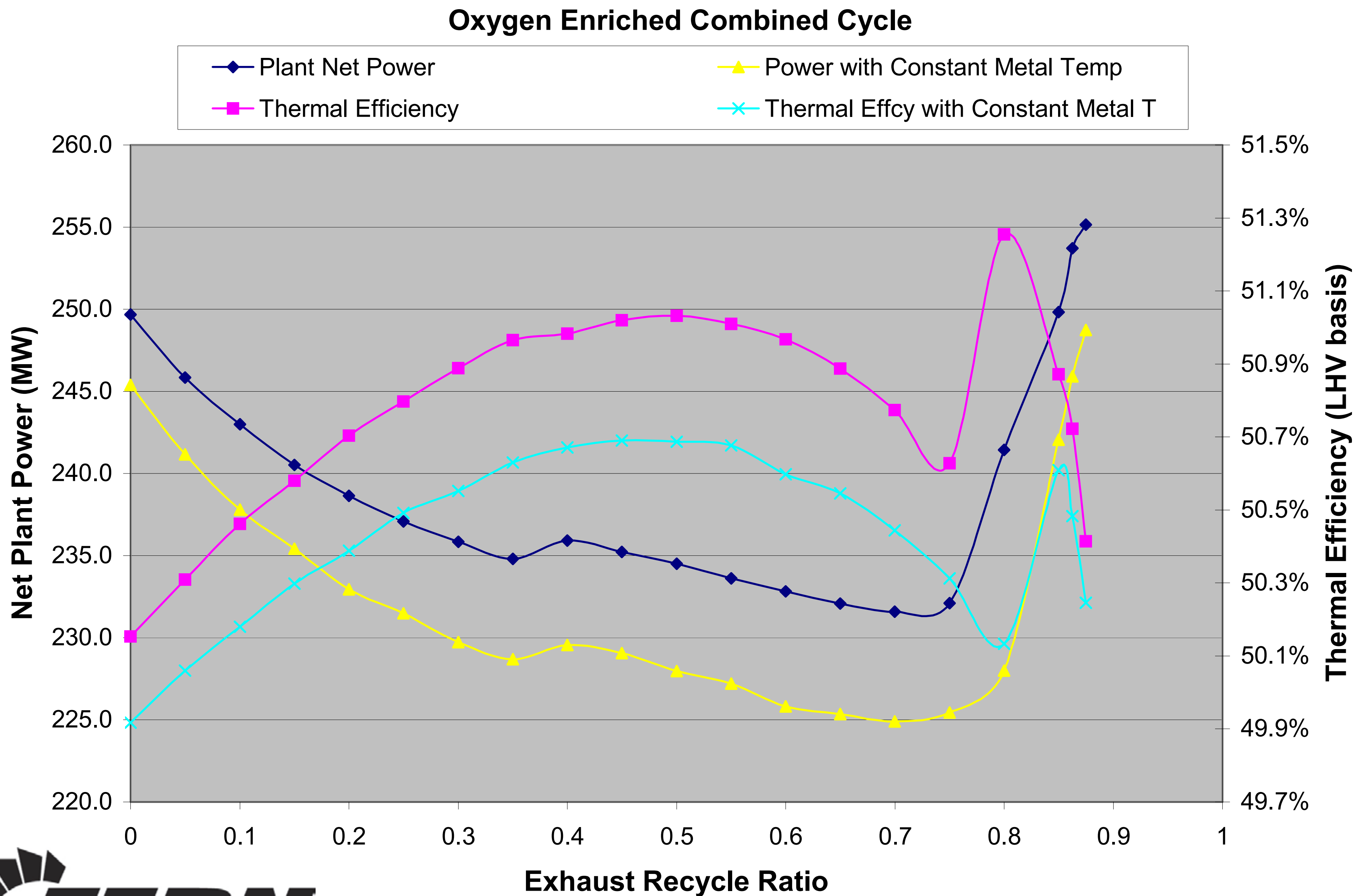


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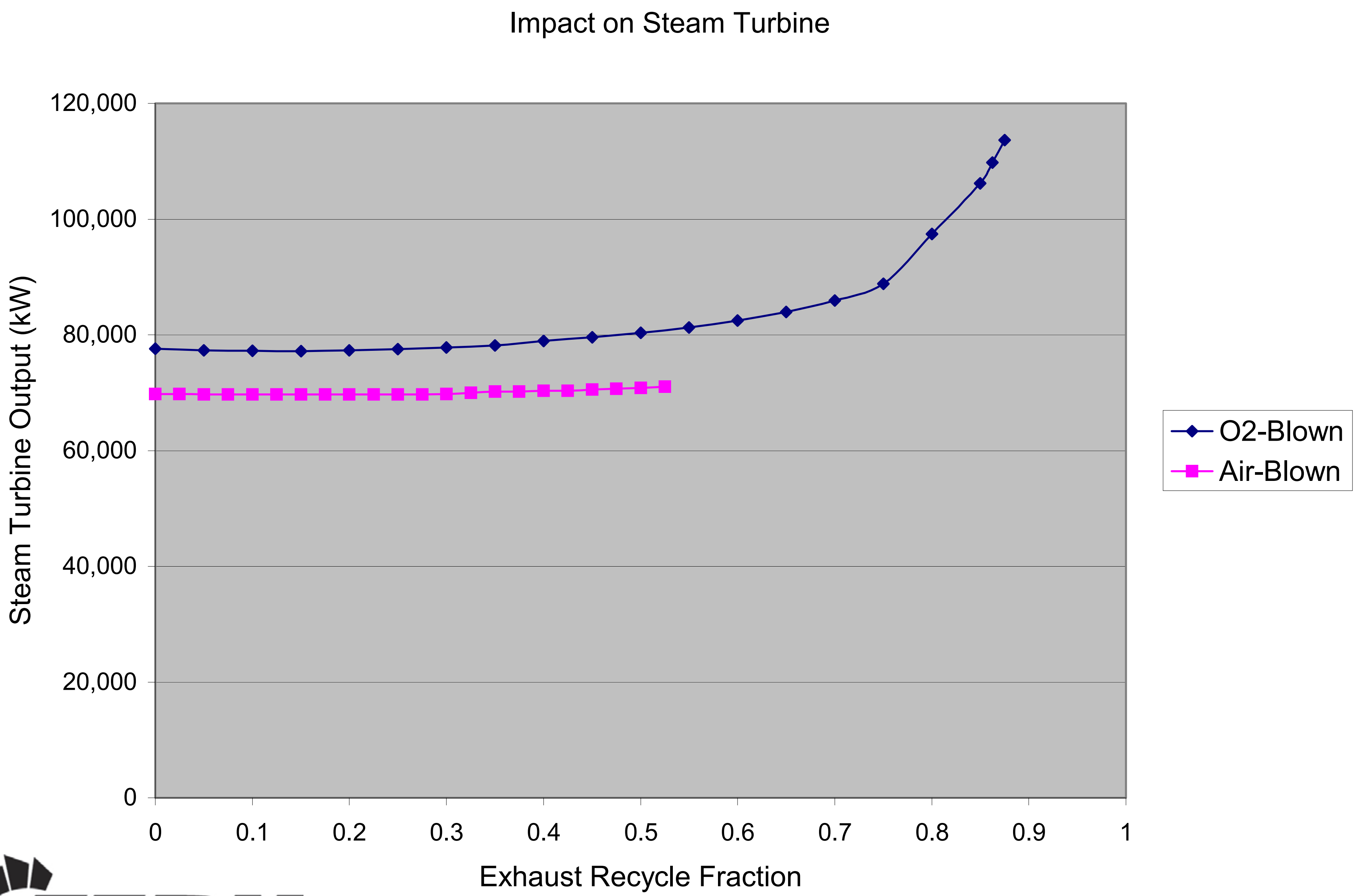


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# Conclusions – Air-Blown Cycle

- Recycling the exhaust of an air-blown combined cycle has a negative impact on both net power output and thermal efficiency
- 52.5% is the maximum fraction of the exhaust which can be recycled
- $CO_2$ volume fraction increases from 4.0% to 8.6%

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# Conclusions – O2-Blown Cycle

- Direct substitution of 99% $O_2$ for air (no exhaust recycle) results in:
  - Small increase in net plant power (excluding power required to produce the $O_2$)
  - 1.7% decrease in thermal efficiency
  - No increase in exhaust $CO_2$ concentration

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# Conclusions – O2-Blown Cycle

- Recycling exhaust has following impact:
  - Maximum fraction of exhaust which can be recycled is approximately 0.875
  - $CO_2$ exhaust concentration exceeds 40vol%
  - Net plant power decreases until recycle fraction exceeds 0.7; at 0.875 it exceeds base case by 3 MW
  - Impact on thermal efficiency is slightly positive
  - Output of steam turbine increases substantially and gas turbine power decreases

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# Conclusions

- High concentrations of $CO_2$ in the exhaust of a combined cycle can only be achieved by using Oxygen in place of air
- However, such a change will significantly impact the thermodynamics of a combined cycle and require the replacement of the steam turbine generator with a larger unit